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MACHINE TOOL TECHNOLOGY: AN AESTHETIC APPLICATION

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INTRODUCTION

This paper is initiated with the reference that one selects process because of aesthetic need. The premise of technology as an end in itself insures the triumph of the means (process) over the ends (aesthetic). Only ones aesthetic ends deserve a primary position in this hierarchy.

This paper is submitted not as a redundant recital of a machine tool technology already supported by vast volumes of technical literature; rather, it seeks to nourish one's aesthetic vocabulary which consequently may demand the use of that technology.

The title, "Machine Tool Technology: An Aesthetic Application", is the result of these thoughts.

A BRIEF HISTORY

Modern civilization owes its form to machine tools. Without them as a necessary condition, the machinery of the Industrial Revolution could not have been built. The development of steel itself would have been of little significance had not the machine tool been present to shape it. Curiously, these machine tools perform in a complex way the same basic operations accomplished by the tools of Stone Age man.

Man, the animal, is distinguished by his ability to make tools and communicate ideas. Tools, when considered as functional extensions of man's limbs, become one of his chief biological characteristics. In evolution, man consistently avoided specialized bodily equipment characteristic of other animals. He retained the flexible five-fingered hand; and after acquiring the ability to walk upright, his hand became free to make and manipulate tools.[1]

Middle Bronze Age civilization saw the development of some important mechanical devices. Among these was the lathe, the oldest of the developed machine tools. The exact place of its origin cannot be established and it is quite possible that its origin was not singular.[2]

It can be clearly established that by the second century B.C. knowledge of the lathe was present throughout most of the European and Near Eastern World. Since the origin of the lathe lacks clarity, details of its spread cannot be established.

Although there is evidence that early lathes were used to turn non-ferrous metal, these machines were primarily woodworking tools. However, by the first century B.C., Celtic arm bands made of shale clearly show the use of the lathe to make body ornaments.

It is surprising to find important innovation during the Dark Ages as evidenced by the significant advances in turning technology. The most important of these advances are: (1) the use of the spring-pole-and-treadle drive; (2) the transformation of the lathe bed and its stocks into rigid structures; (3) the introduction of continuous motion drive of the workpiece; (4) the appearance of the first device for holding and controlling the cutting tool mechanically.[3]

These Dark Age advances began a process of refinement leading toward building skill into the machine. Specifically, the spring-pole-and-treadle drive freed the hands of the operator for more accurate tool manipulation. Bed rigidity reduced machine vibration and tool chattering. The continuous motion drive replaced the spring-pole-and-treadle drive to provide continuous rather than intermittent cutting. The introduction of mechanical cutting tool control provided the means for precise progression of the cutting tool along the workpiece.

By the end of the eighteenth century, metal-cutting lathes were prevalent. Diderot's *Encyclopedia of Trades and Industry* gives this clear reference.[4] Lathes were used to shape convoluted rims on gold platters, to cut threads in ferrous and non-ferrous metals, and to apply surface decoration.

Of particular interest is the development of the ornamental lathe. These machines, first documented in the late sixteenth century, include the use of eccentric cams and templates. The Holtzapffel lathes of the late eighteenth century (fig. 1) exhibited headstock indexing, revolving cutters, and eccentric chucks. These ornamental lathes supplemented machine form vocabulary by producing eccentric as well as asymmetric shape. Much of the technology found in these machines surfaced years later in the universal milling machine.

The components of the lathe as we know it were known and used during the eighteenth century. However, it was Henry Maudslay, in 1797, who provided the synthesis yielding the form fundamental to the modern industrial lathe.

Since Maudslay, the lathe has been developed to meet the demands of new materials and products. Yet, the aesthetic of lathe turned form remains well founded in those that preceded him.

The development of the industrial milling machine began in the early nineteenth century with the inventors Eli Whitney and Robert Johnson. These early machines, used primarily in small arms production, were essentially rotary files capable of only shallow cuts.

By 1830, the basic elements of the milling machine had been introduced, and by 1860, the milling machine had secured a place in the metal trades. However, the ancestor of the modern milling machine was not provided until 1861. Joseph Brown's *Universal Milling Machine* was the synthesis of the preceding sixty years. This machine, developed to machine flutes (grooves) into twist drills, increased power and rigidity, improved feed, and introduced the knee and column system. Increased power and rigidity with improved feed reduced cutter chatter and extended cutter life. The knee and column system solved the problem of vertical cutter adjustment that had plagued milling machine design until that time.

In addition, Joseph Brown replaced the rotary file type cutter with the segmented tooth cutter as is common today. Each cut taken with a rotary file type cutter only changed the surface of the workpiece while a cut taken with the segmented tooth cutter could substantially alter the form of the workpiece. The rotary file type cutter was hand-made and when dull required annealing, refiling, and subsequent hardening and tempering. Brown's cutter eliminated this cumbersome process to require only simple grinding upon dulling a cutter.

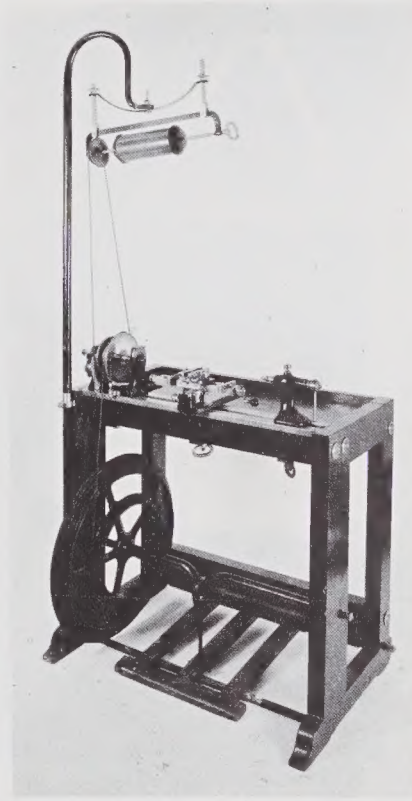


Figure 1

Brown's machine and cutter had set the stage for the developments of the twentieth century that were to follow; greater strength and rigidity, faster cutting speeds, the inclusion of the electric motor, and fully automatic operation.[5] Greater power and rigidity allowed for increased precision with additional stock removal. Full automation, in the form of computerized milling machines, provided simultaneous stock removal on three aces. All of these provided greater efficiency with greater diversity of form.

The history of machine tools is vast and complex The preceding sketch can only offer a very superficial survey of the three thousand or more years that have passed since the first machine tools were used. However, it does inform the individual that in these processes too, there is tradition.

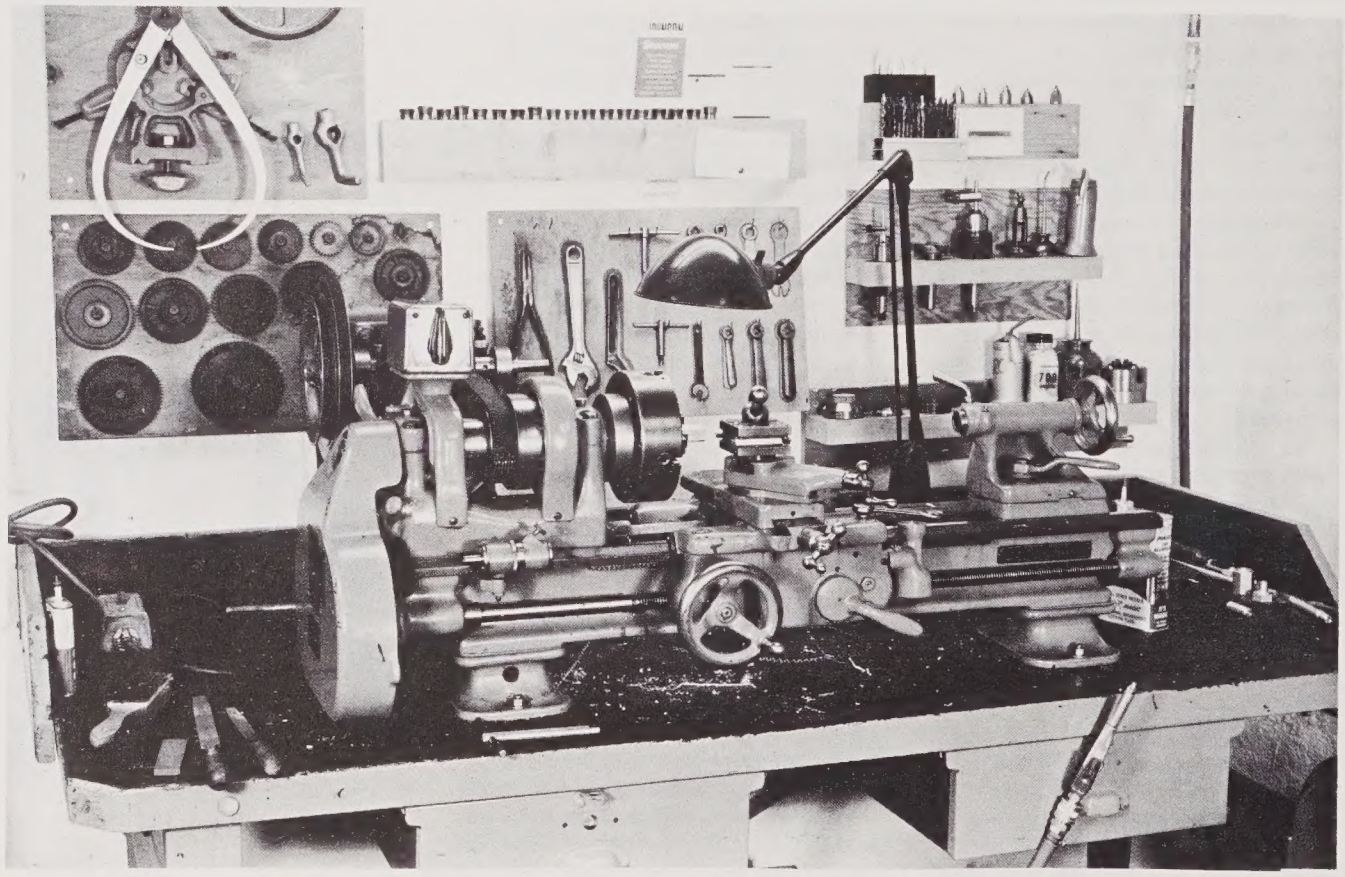
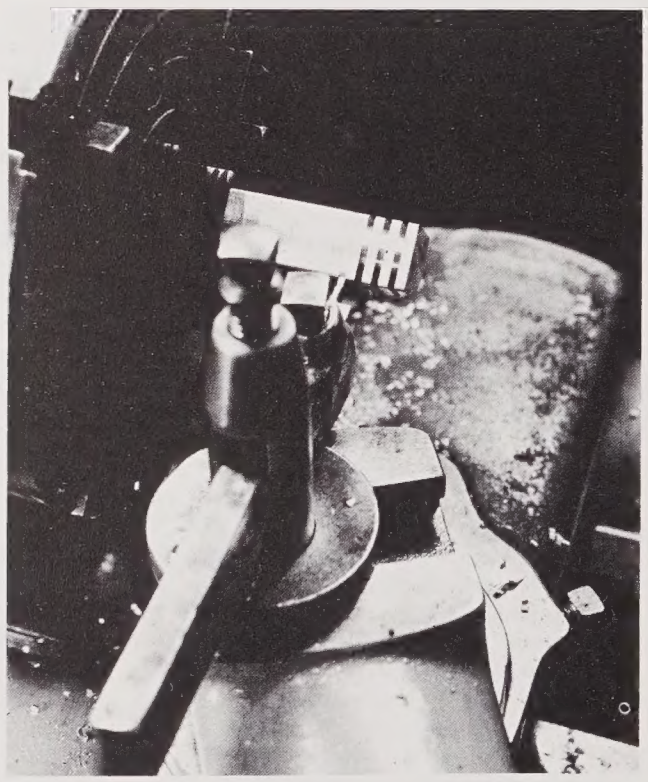


Figure 2

Figure 3



The distinguishing feature of the lathe, (fig. 2) is that it produces cutting action by turning the workpiece against the edge of the tool. As the workpiece revolves, the tool feeds into or across it. Turning is a subtractive process usually producing a surface that curves in one direction and is straight in another. The form of a cylinder illustrates this statement.

The lathe turned aesthetic is founded in and dependent upon this simple cylinder. The variations resulting from applying this basic premise are infinite.

Lathe products are three dimensional. Analysis of this fact indicates that three-dimensional form results only because the work is being rotated. In contrast, the movements of the cutter are graphic or two dimensional. Movement of lathe cutters is only longtitudinal, cross or a compound of the two. (Refer to the nomenclature diagrams in the glossary.)

With this contrast in mind, let us proceed to manufacture a sample that illustrates the point. The workpiece is 6061 T6 aluminum, 5/8" square in cross section, approximately 4" in length. The workpiece is secured in the chuck and subsequently rotated.

Initial cutting occurs when the tool is moved into the rotating workpiece. Slots, the negative area, and fins, the positive area, result (fig. 3). This movement of the tool is graphic only utilizing the cross feed.

Inspection of the cut reveals several visual facts: (1) the sides of the cut are flat, graphic form, and (2) the bottom of the cut produces a disc which is comparable to the fundamental cylinder discussed earlier. Already the two-dimensional three-dimensional paradox is visually apparent.

To this point, all cutting has been external and applied by cross feeding. By drilling along the longtitudinal axis, (fig. 4), internal cutting results. A standard drill chuck is inserted into the tailstock, the twist drill is secured, the work is rotated, and the drill is fed into the workpiece utilizing the tailstock mechanism resembling that of a drill press.

The cutting action itself is visually fascinating since the workpiece is rotating and the twist drill is stationary. Drilling operations on any other machine are accomplished with stationary workpiece and revolving twist drill.

Analysis of the drilled hole again supports the fundamental aesthetic of the cylinder. However, this cylinder is in negative rather than positive form.

This internal cylindrical form can be easily altered. In this sequence, a tap will be used for that purpose. A tap with tap wrench is started into the hole utilizing the tailstock for alignment and support (fig. 5). Tapping is done while the machine is idle. This is a manual operation.

Superficial inspection reveals a threaded hole. Closer inspection shows that this threaded hole is actually a helical groove. In other words, further development of form.

This helical groove is a variation of the basic cylinder. It is a compound of cross cutting, the groove itself, and longtitudinal advance, the helix. Again we find two-dimensional movement resulting in three-dimensional form due to rotation of the tap.

In order to expose internal form and add visual complexity, the end of the workpiece was split (fig. 6). The result is a cross-sectional view of all operations performed which further develops the aesthetic.

The cross-sectional view clearly manifests the simultaneous existence of the two-dimensional, the top edge and the three-dimensional, the outside edges and the internal cavity. The cross-sectional view reinforces the premise of variation of the cylinder and suggests that a component in that variation is cutter shape.

Lathe toolcutter bits are supplied as blanks. Their shape is determined by the machine operator.[6] These bits are given their shape by grinding on a standard tool grinder.

Tool bit shape is infinite. This illustrates another point worth discussing; complexity of form. When infinite tool bit shape is applied through cross longtitudinal or compound feed, the visual result is a multiple and by definition, complex.

This complexity, as process and as form, can be very intimidating. One must remember that visual complexity is easily built by overlapping different systems. Systems, represented by the turning operations in figures 3-6 are applied process.

It is not difficult to follow the synthesis in figures 3-6. However, if one does not consciously analyze the visual result of this synthesis, imitation rather than learning will result.

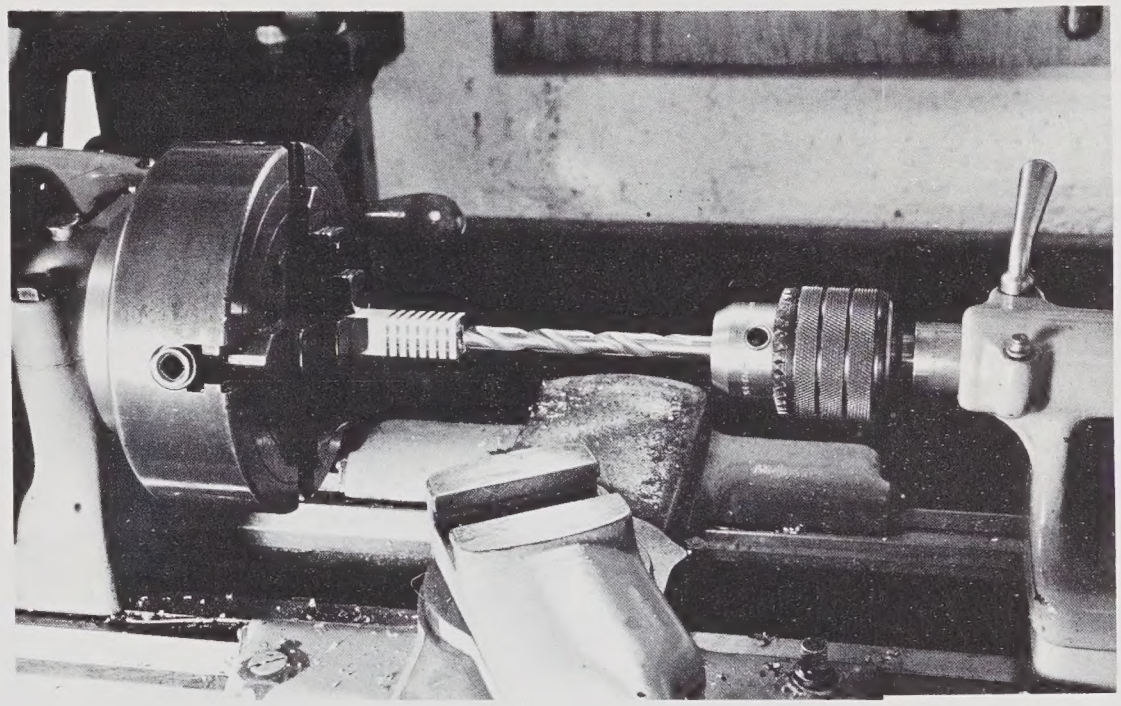


Figure 4

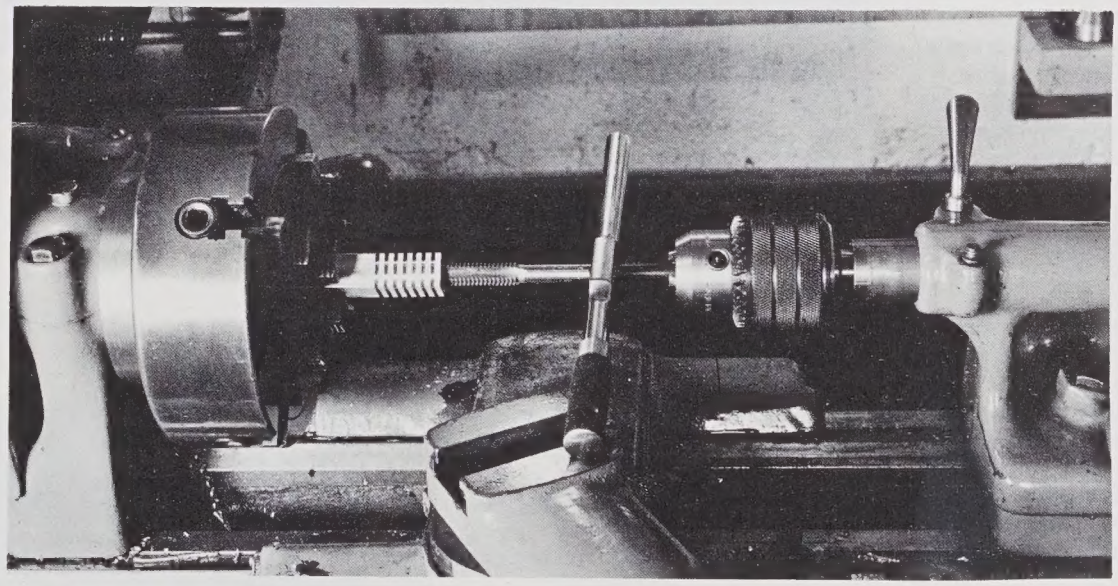


Figure 5

Figure 6

The shaper (fig. 7) is a tool used to machine flat surfaces by performing successive reciprocating (alternating forward and backward) cuts over the workpiece. The shaper uses a single cutting tool very similar to a lathe tool bit. The workpiece, securely fastened to the table, may be moved transversely (cross feed) by hand or automatic feed beneath the cutter.

The distinctive element in shaping is the use of reciprocating motion to form a straight line. Shaping is a subtractive process that may render form as texture, relief or volume. Therefore, the aesthetic result of shaping will always be founded upon this linear, subtractive relationship.

With line and texture in mind, let us proceed to manufacture a sample that illustrates the point. The workpiece is 6061 T/ aluminum, 3/16"x 1½"x4½". The workpiece is secured in a vise which is mounted on the table. The cutting tool head (see nomenclature diagram in glossary) is lowered until the tool bit touches the work. The machine is switched "on" and a line is cut (fig. 8).

Before proceeding, an understanding of feed is necessary. Feed is defined as the distance the work is moved transversely toward the cutting tool for each forward stroke of the ram.[7] By controlling the rate of this transverse (cross feed) advance, we control texture.

This rate of transverse advance is nothing more than frequency of repetition. Within a defined distance, if the frequency of traverse is short in interval, we have fine feed and subsequently fine line texture. Within the same distance, if the frequency of traverse is long in interval, we have course feed and subsequently course line texture.

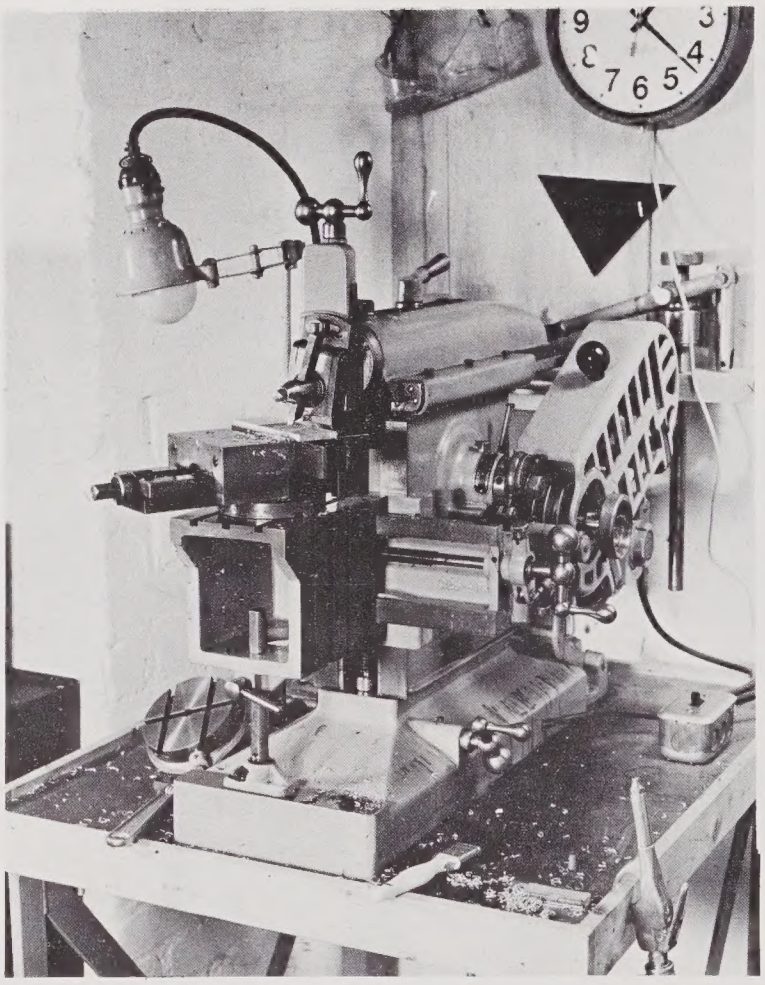


Figure 7

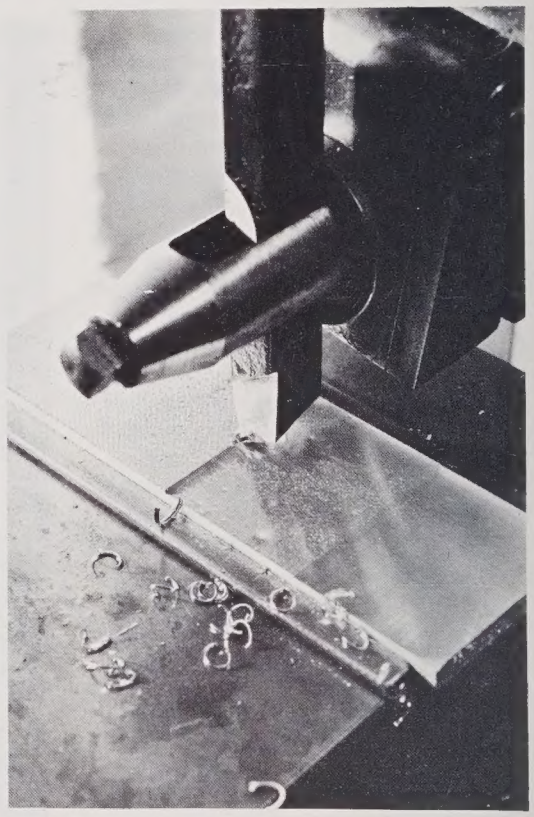
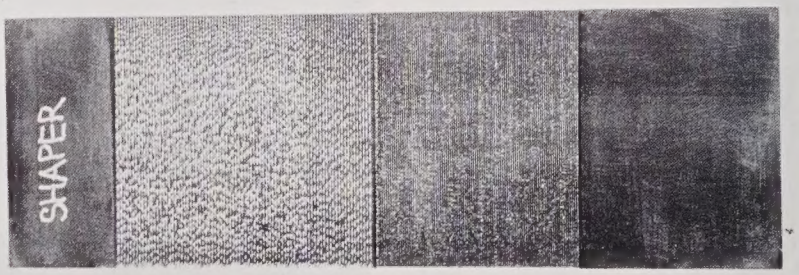


Figure 8

This principle of linear repetition as texture is illustrated in fig. 9. The bottom of the sample is fine line texture, followed above by medium line texture, and finally course line texture.

Figure 9



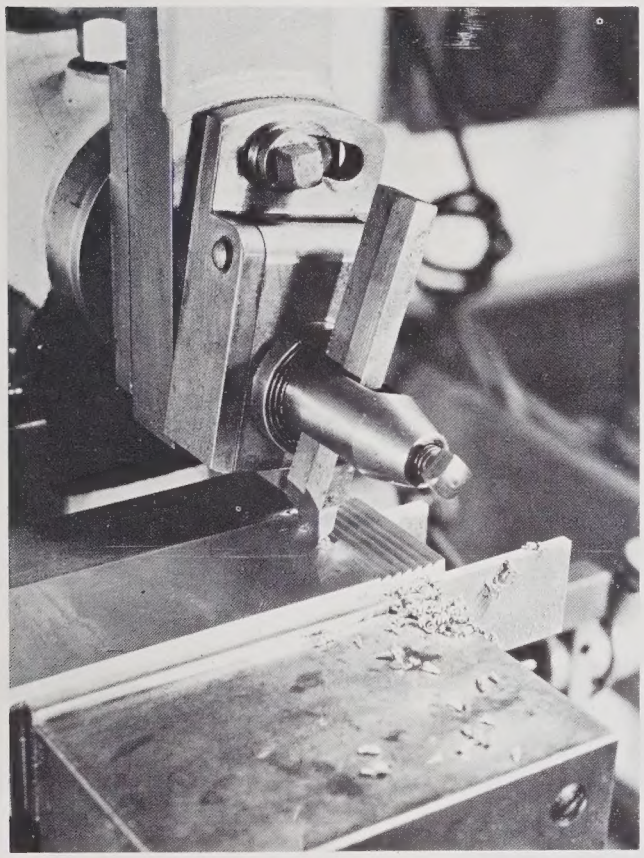


Figure 10

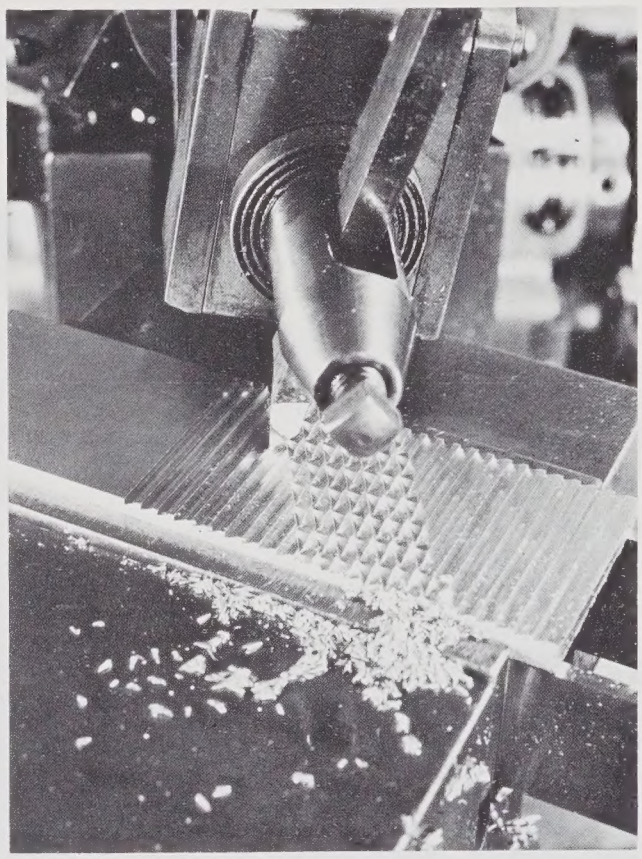
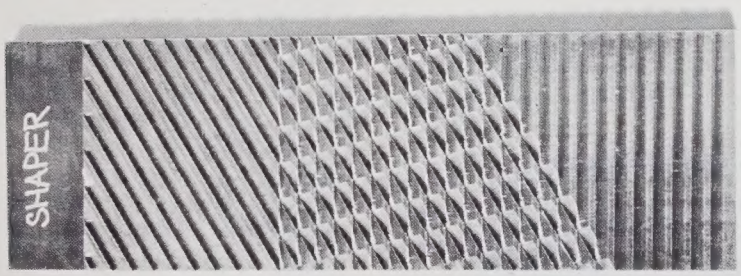


Figure 11

Figure 12



In this complex pattern relief, the depth of cut and the interval of traverse frequency (feed) remain unchanged. Cut angle is the variable. However, it is overlapping (fig. 12) that is the agent of complexity.

Figure 12 is explicit as an example of overlapping systems. The top and bottom section of the sample show simple pattern relief. The bottom area is horizontal pattern and the top is angled pattern. The middle area is a complex pattern developed by overlapping the two.

Active acknowledgement of basic aesthetic principles as applied through technical process is essential. The passive rendering of technique can only result in a mere report of process.

This sample (fig. 9) is clearly a basic cause and effect relationship. In terms of technology, the cause, cutter reciprocation and work traverse, yields the effect, repetitive linear cuts. Aesthetically, the cause, repetition of parallel lines, yields the effect, texture.

This aesthetic cause and effect relationship is a rather general axiom. Specificity is only realized through the application of technical process. In this case, shaping is that technical process. Hence, the result is specific aesthetic application.

By increasing the intervals of traverse frequence and by increasing the depth of cut, one finds the beginnings of pattern as relief (fig. 10). The fundamental subtractive line and the variable traverse frequency (cross feed) are visually present. Together they develop pattern. Depth of cut alone provides relief.

Figure 10 illustrates simple pattern relief development. Complex pattern relief is developed by the overlapping of systems (fig. 11). Here, the only variable is the angle of cut. This angle of cut is achieved by rotating the vise on the table.

The milling machine is a type of machine tool in which the work is fed against a rotating cutter, which is mounted in the revolving spindle of the machine.[8] (See nomenclature diagrams in the glossary.) The vertical milling machine (fig. 13) is distinguished by the fact that the spindle is normally in a vertical position.

The workpiece is held securely on the table of the machine or in a holding device clamped to the table. The table may be moved in longtitudinal, cross and vertical directions.

The vertical mill offers diversity not found in other machines. This diversity offers visual results that can only be described as vast. However, one may select a particular characteristic of this machine and illustrate that characteristic.

The use of a revolving cutter is a fundamental characteristic of milling machines. In the case of the vertical mill, the visual result of the revolving cutter can become a distinctive visual element. Rotation describes a circle or in the case of incomplete rotation, an arc. That circle or a portion of it, its arc, is the particular characteristic the following samples illustrate.

Longtitudinal and cross feed produce linear qualities since these two feeds are essentially graphic movements. The vertical traverse produces relief and subsequently the third dimension.

In figure 14, a piece of 6061 T6 aluminum, 3/16"x1½"x4½" is secured in a vise which is clamped to the table. The machine is switched "on" and the cutter begins rotation. Depth of cut is selected through use of the vertical table traverse. Removal of stock is accomplished by feeding the workpiece into the cutter.

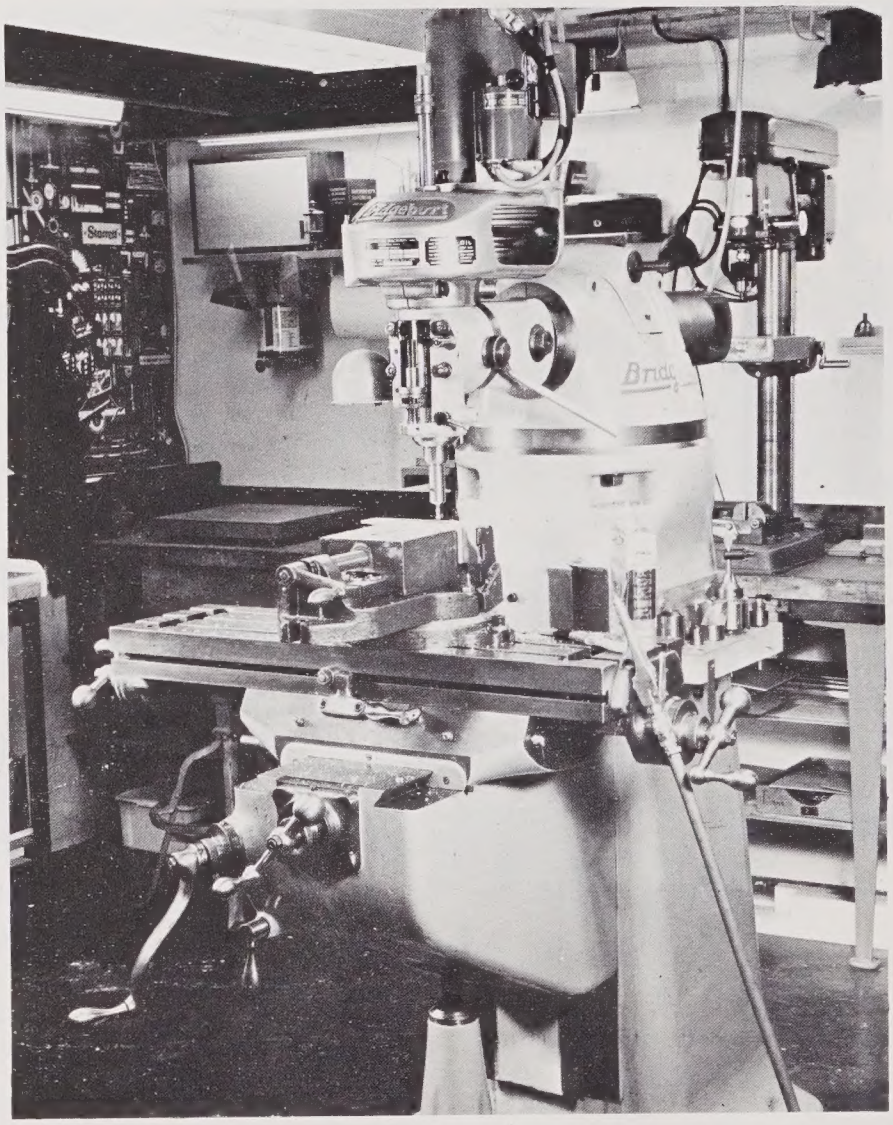


Figure 13

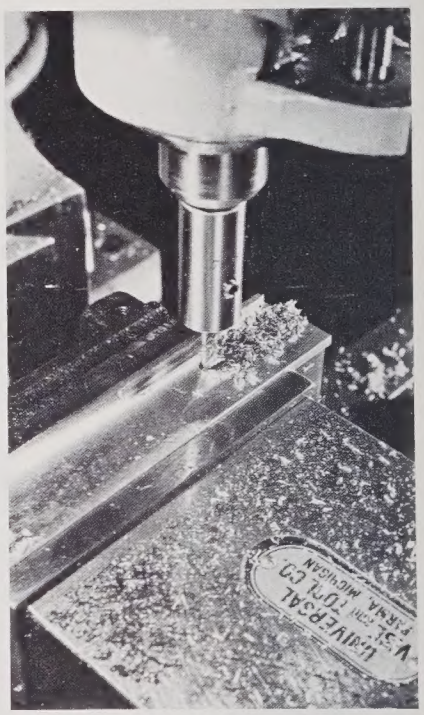


Figure 14

This result (fig. 15) illustrates the most obvious aesthetic fundamentals of the revolving cutter. Visual variation is easily achieved by changing cutter diameter, and any or all of the three feeds.

The sample (fig. 15) illustrates the following visual results. Work fed longtitudinally produces a line with width equal to the diameter of the cutter. The termination of that line is an arc with radius equal to that of the cutter. Repetition of that line is controlled through cross feed.

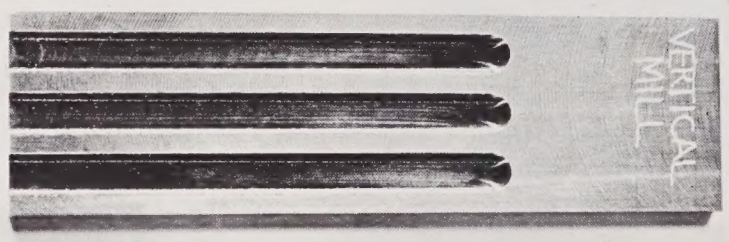


Figure 15

A more complex variation of the visual results of the revolving cutter may be achieved by tilting the head at a compound angle (fig. 16).

By using longtitudinal and cross feeds to position the cutter repetitively, a grid system is developed. This grid is simply a repetition of form in two dimensions (fig. 17). Cutting or removal of stock is achieved through use of the vertical table traverse alone. The table is raised to produce cutting at a specific depth and then the table is lowered. Notice that the visual result is still founded in the revolving cutter.

If depth of cut remains constant and the longtitudinal or cross feeds are used to produce cutting, the visual result changes (fig. 18).

The bottom section of the sample in figure 18 is the grid system discussed earlier. The middle section is the result of cutting through use of the cross feed. The intervals of cut are selected through the vertical traverse.

Of significance is the cross sectional view of this cut. It is not a single arc, rather a form that is the combination of the two arcs. This combination yields the form.

The top section of the sample (fig. 18) is the result of cutting through use of the cross feed, and the depth of cut through the vertical traverse.

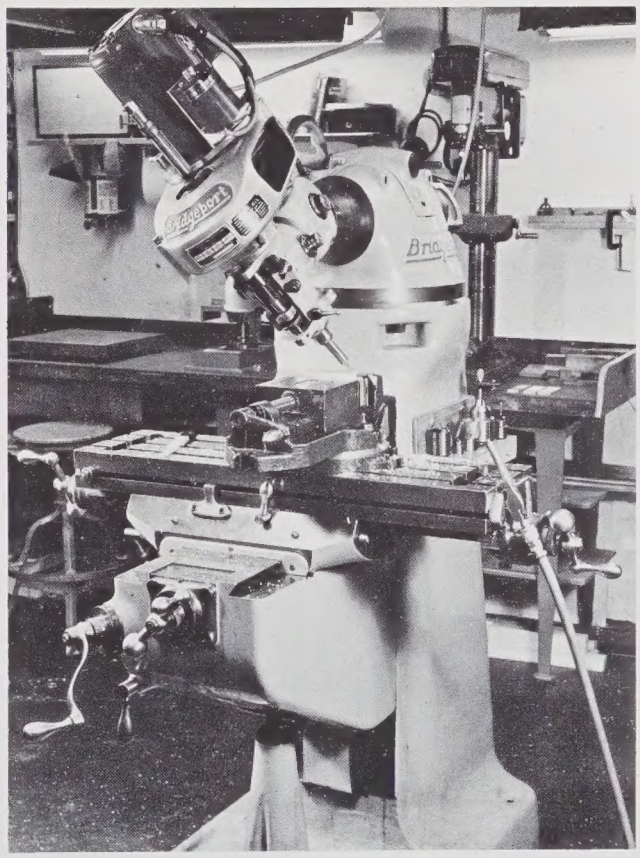
The cross sectional view of this cut is a mirror image of the cuts taken in the middle section. Note the visual results achieved by terminating the cut within the borders of the stock. The aesthetic, although complex in terms of process, remains founded in the arc of the revolving cutter.

Variation of the forms in figure 18 may be achieved by changing the angle of the head, the diameter of the cutter, and any or all of the three feeds.

A rather curious aesthetic result that is present in figure 18 is that of form reversal. The reader is now prejudiced since subtraction (stock removal by cutting) has been discussed. However, without this prejudice, one would have difficulty distinguishing whether the forms were raised or recessed. This dicotomy could easily become a premise for one's aesthetic sensibilities.

If one fails to acknowledge aesthetic premise, the resulting work will have no real significance. In other words, the visual result of technical process would lack the direction given by an aesthetic. Consequently, the lack of direction results in a mere record of cause and effect.

Figure 16



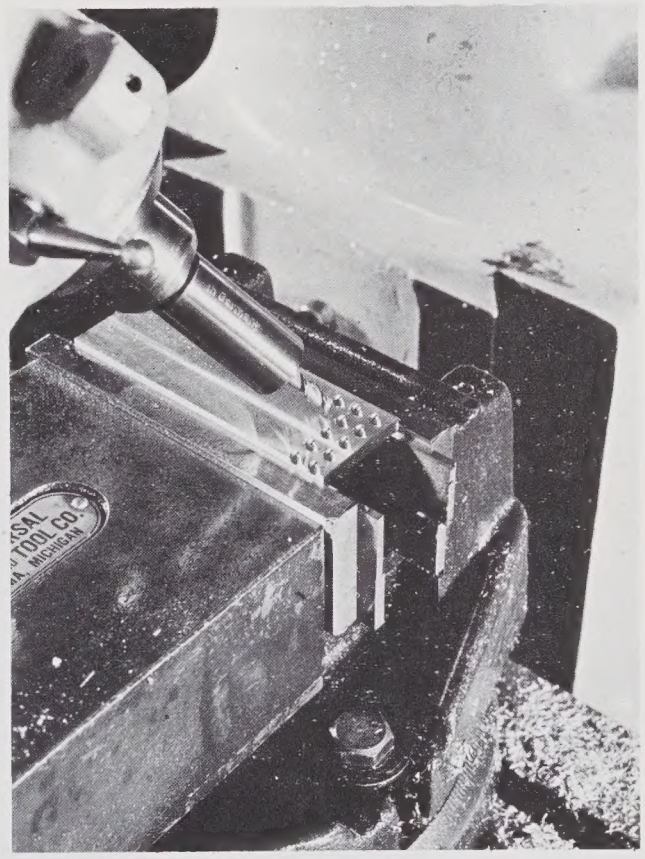
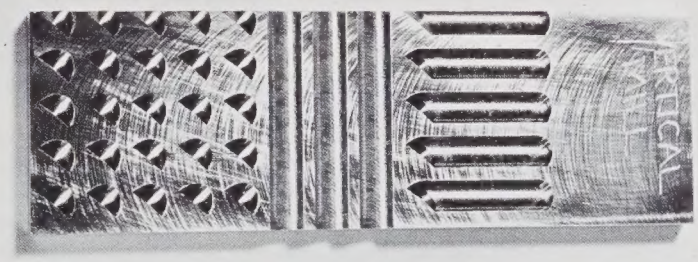


Figure 17

Figure 18



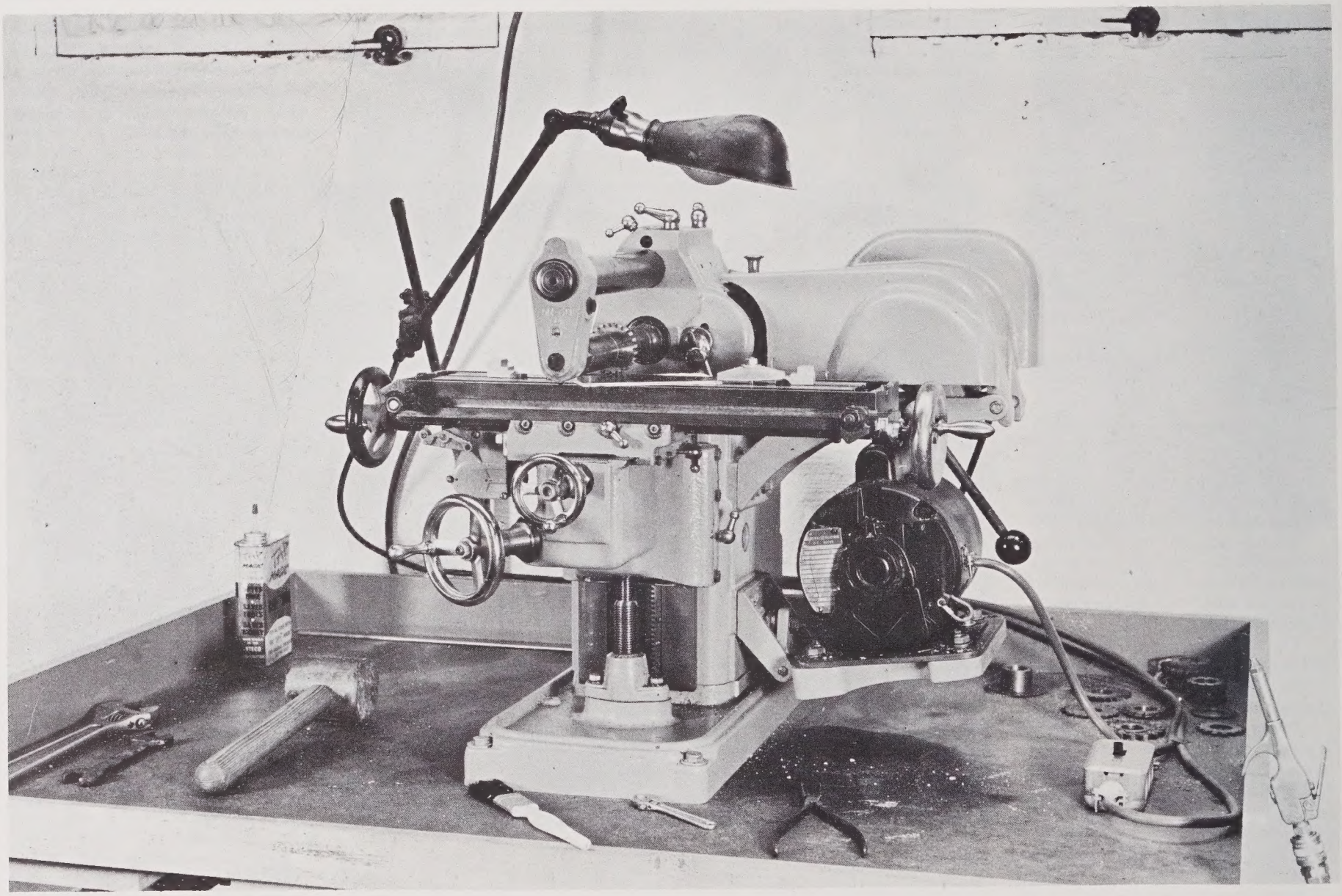


Figure 19

The horizontal milling machine (fig. 19) is distinguished from the vertical milling machine by featuring a horizontal spindle. All other features of the horizontal mill parallel those of the vertical mill.

The variation of cutter shapes used on the horizontal mill is of primary aesthetic interest. Cutter shape is the primary interest since the basic aesthetic is that of work being fed into a revolving cutter resulting in linear form. The cutter shape acts to contour that line.

A piece of 6061 T6 aluminum, 1/8"x2½"x5" will act as the sample. Figure 20 illustrates a milling operation using a cutter with serrated teeth. Each pass of this cutter leaves a line equal to the width of the cutter with a contour that is the reciprocal form of the cutter.

Traverse of the longtitudinal feed produces line. Traverse of the cross feed produces repetition of that line. Depth of cut (vertical traverse) produces relief in that line.

By changing the cutter (fig 21) the visual result of milling changes significantly. The new cutter, much thinner than the previous one, resembles a saw blade. The visual result of this cutter resembles a slot.

All of the feeds used with the previous cutter remain unchanged. With the one variable, cutter shape, two distinctive lines have been produced (fig. 22).

Since the longtitudinal feed always moves perpendicular to the spindle of the horizontal mill, diagonal cuts can only be achieved by angling the work. The workpiece may be secured to the table at any angle.

A common theme continually surfacing in machine tool process is that of precision. The machine assists the operator in working to close tolerance.

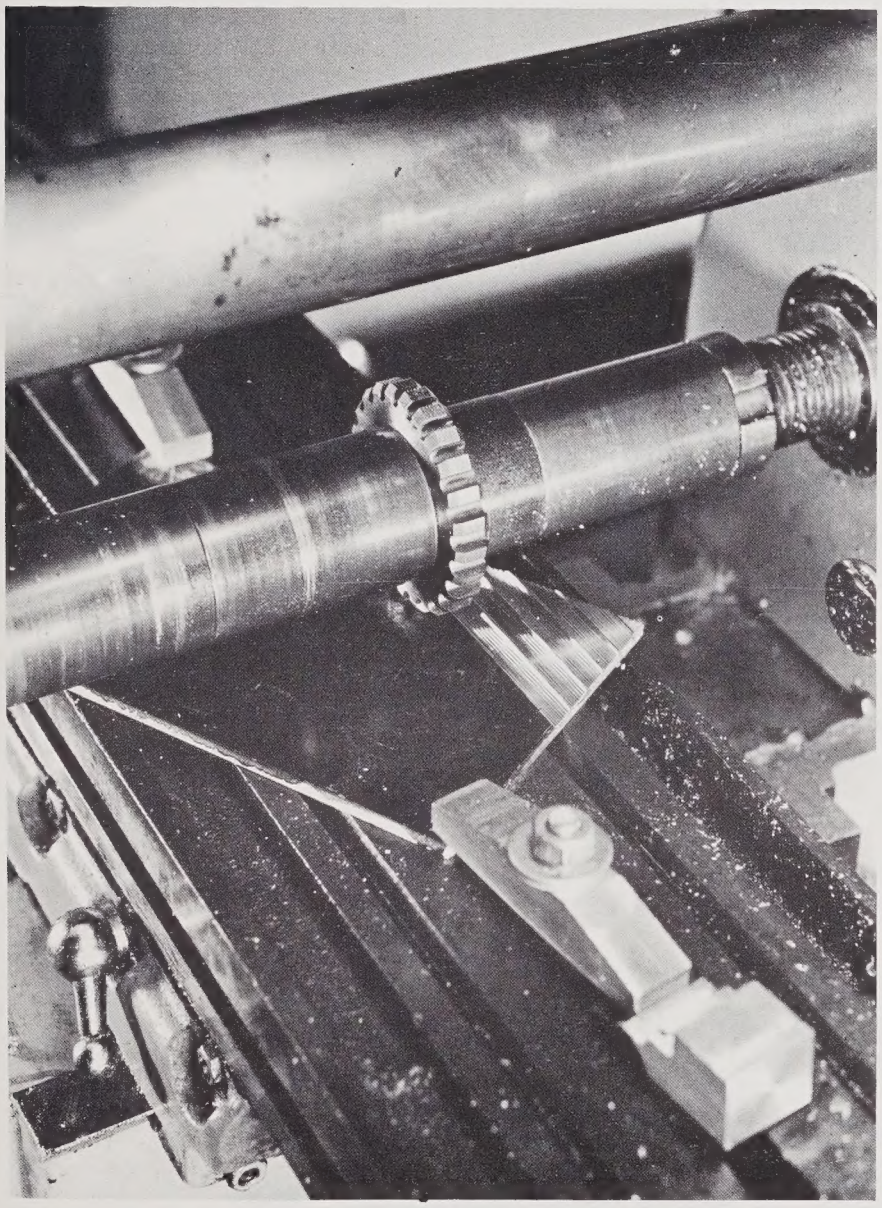


Figure 20

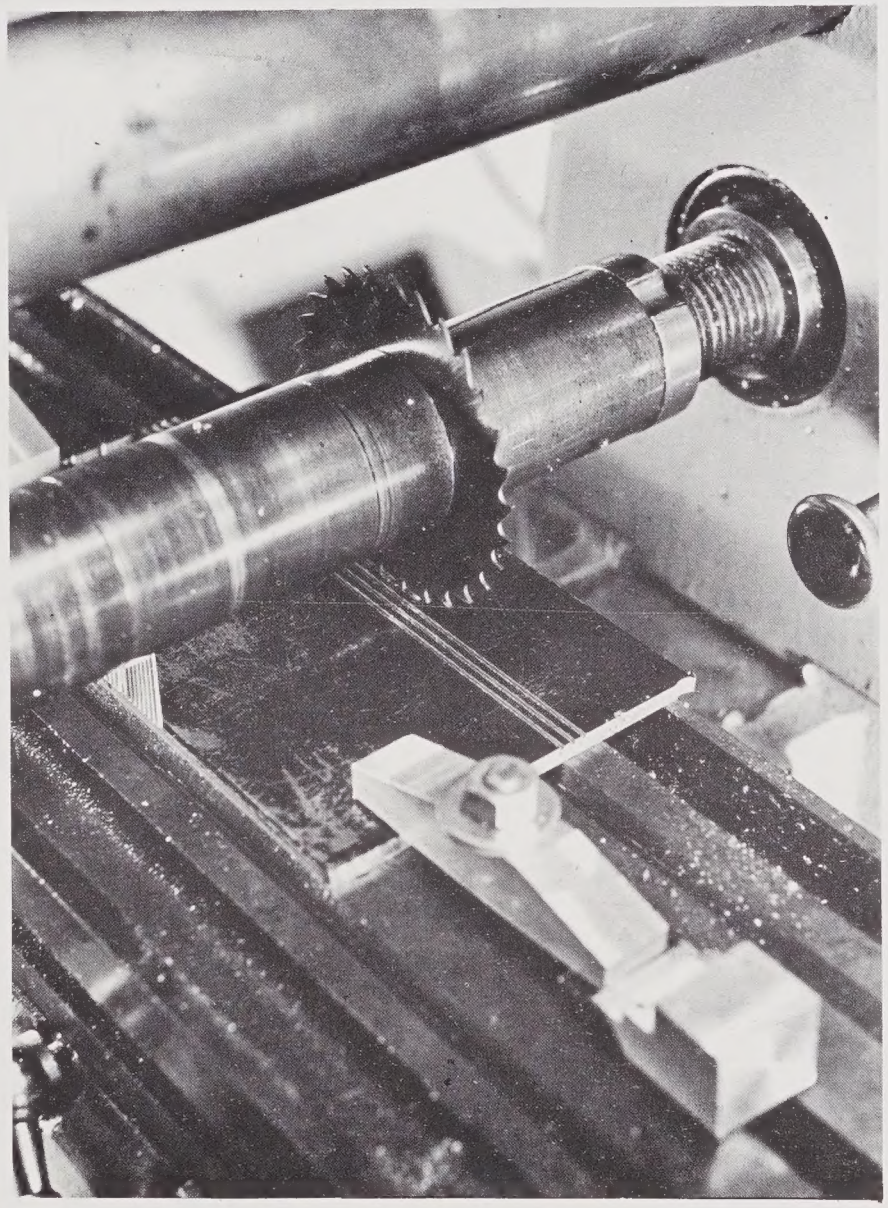


Figure 21

Precision is a matter of degree. What is precise by hand may be relatively imprecise by machine. Although the machine offers precision, it also makes error more noticeable.

Curiously, as one's aesthetic needs demand use of the machine tool, the machine tool reciprocally demands more precision from the operator.

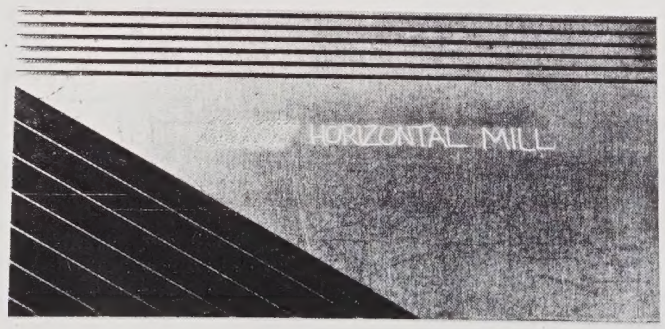
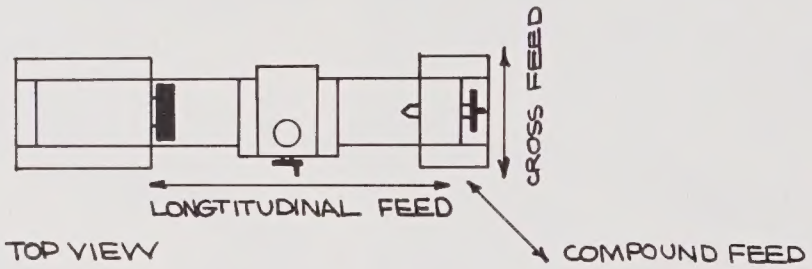
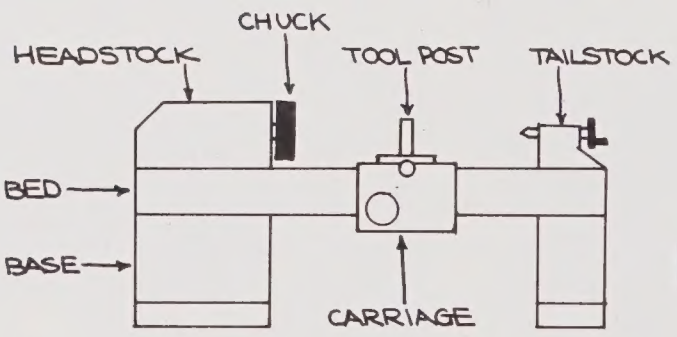
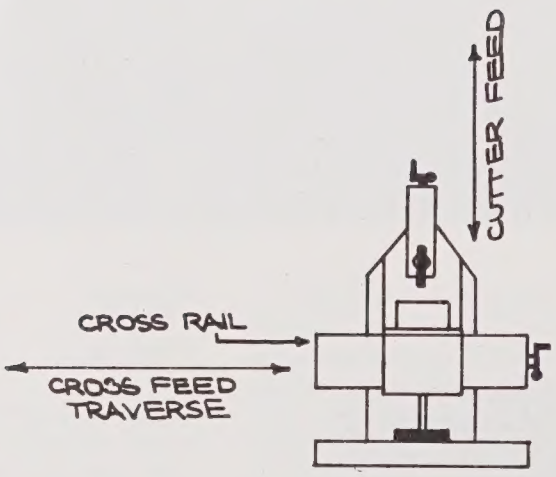


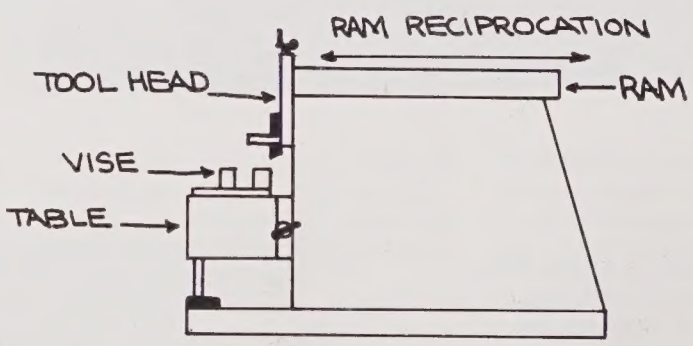
Figure 22



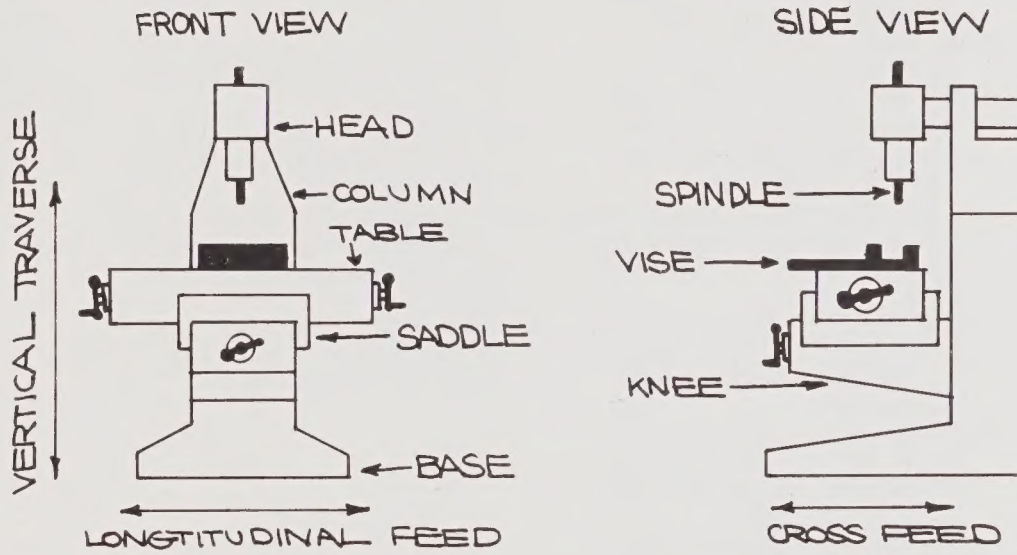


LATHE

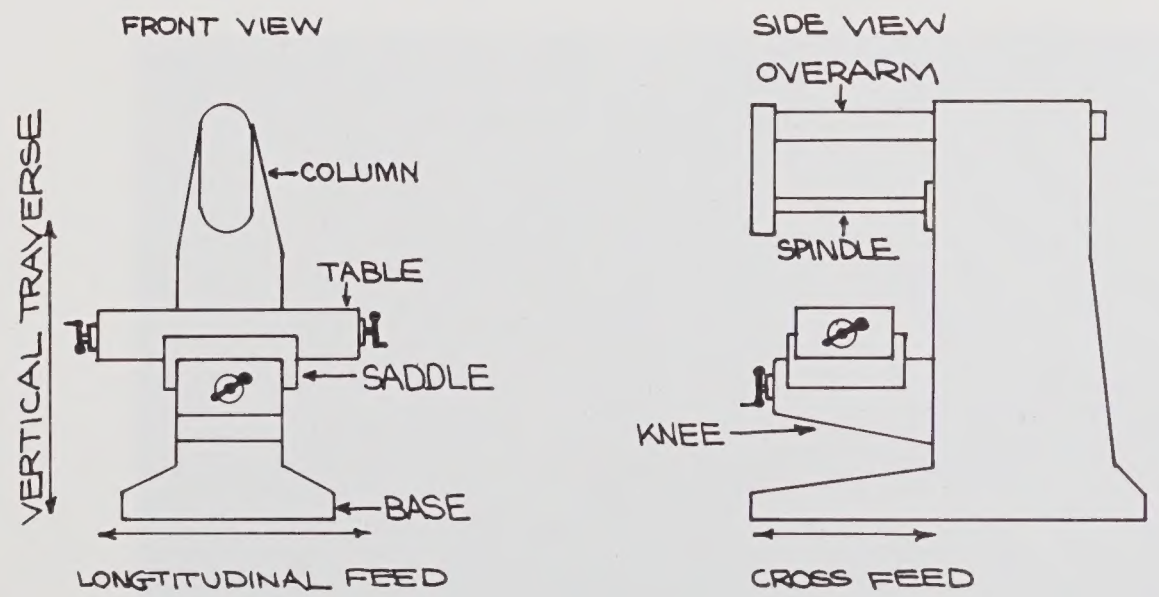




SHAPER



VERTICAL MILL



HORIZONTAL MILL

FOOTNOTES

[1]Kenneth P. Oakley, *Man the Tool Maker* (London: Trustees of the British Museum, 1972), p. 1.

[2]Robert S. Woodbury, "History of the Lathe to 1850," *Studies in the History of Machine Tools* (Cambridge: M.I.T. Press, 1972), p. 23.

[3]Ibid., p. 38.

[4]Denis Diderot, *Encyclopedia of Trades and Industry* (Paris: 1763; reprint ed., New York: Dover Publications, 1959), plates 405, 406.

[5]Robert S. Woodbury, "History of the Milling Machine," *Studies in the History of Machine Tools* (Cambridge: M.I.T. Press, 1972), pp. 48-49.

[6]South Bend Lathe Co., *How to Run a Lathe* (South Bend, Indiana: South Bend Lathe, 1966), p. 34.

[7]S.F. Krar, J.W. Oswald, and J.E. St. Amand, *Technology of Machine Tools* (Toronto: McGraw-Hill of Canada, 1969), p. 201.

[8]W. J. McCarthy and R. E. Smith, *Machine Tool Technology* (Bloomington, Illinois: McKnight and McKnight, 1968), p. 317.

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CREDITS

1. Photograph of the Holtzapffel lathe, Figure 1, from the North American Center for Ornamental Turning at the Rochester Institute of Technology.
2. All additional photographs and drawings by the author.

Gary Griffin, "Brooch 77-1", aluminum, 3"h x 6"l – machines used were vertical mill and lathe